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OPERATION AND MAINTENANCE OF IRRIGATION SYSTEMS

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PAPERS

OPERATION AND MAINTENANCE OF IRRIGATION SYSTEMS

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Synopsis

A description of the problems of operation and maintenance of irrigation systems, particularly in the United States, is presented in this paper. Operating procedures based on deliveries of water in accordance with natural flow rights, on demand, in rotation, and on advance orders are discussed. Causes of operating waste are described and the need for measurement of water is emphasized. It is pointed out that efficient operation of irrigation projects depends on the maintenance of all storage, diversion, distribution, and drainage works in good condition at all times. Various maintenance problems are described, and attention is called to the need for more efficient machinery and equipment. Certain records of costs of operation and maintenance of irrigation projects are presented and the importance of better cost accounting is emphasized.

Introduction

Most ancient civilizations were dependent on irrigation because they developed in regions where rainfall was insufficient to support agricultural economy. Hence, it is not strange that clay tablets from the ruins of Babylon, hieroglyphics cut in rocks along the Nile, and the literature of many other races describe problems of operation and maintenance of irrigation systems. If the prehistoric peoples who built irrigation works in the Americas had left a written record, they too would probably have described such problems. In the twentieth century of the Christian era there are only better tools with which to maintain irrigation systems in good condition so that water may be delivered to each farm as needed for beneficial use without unnecessary waste.

No sharp line can be drawn between the functions of operation and maintenance. It may be stated that operation includes everything which relates directly to the delivery of water to farms, whereas maintenance embraces the repair of structures and cleaning of canals and drains. On small projects the distinction is largely academic because the works are usually kept in repair

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by the same forces who handle the diversion and delivery of water. Even on large projects where the irrigation season is short, the system may be maintained in large part by operating personnel. However, for administrative and cost accounting purposes, it is advisable to distinguish between the functions of operation and maintenance.

Operating Procedures

Although the basic requirements of efficient operation are the same everywhere, many problems are peculiar to a single irrigation system or at least to projects having similar characteristics.

In northern regions, the growing season is short; in other areas, water is used for irrigation throughout all the months of the year. On some projects, the entire supply is controlled by storage dams; on others, a reservoir on one branch of a river must be operated to compensate for fluctuations in the discharge of another; and in a number of cases, there are no storage works. In certain instances, such as on the Rio Grande Project in New Mexico and Texas, waste water from one unit is rediverted for irrigation use in the next valley downstream, whereas in others, such as the Imperial Valley in southeastern California and the Closed Basin in San Luis Valley, Colorado, no part of the water diverted returns to the stream system.

Differences in rights to the use of water must also be taken into account in the operation of irrigation systems. Generally these have different priorities depending on the time when the particular parcels of land were first irrigated, because water rights can be acquired under the law of most western states only by appropriation and subsequent beneficial use. Rights to divert from a stream are not changed when the supply is regulated; water must be delivered on demand in the order of priorities as if no storage dam had been built. There are sometimes rights of different priority to the use of stored water, usually where the area of a project has been enlarged coincident with the construction of supplemental reservoirs. In the Salt River Valley of Arizona the situation is further complicated by the fact that underground water supplies have been developed partly on behalf of all the lands and partly for the benefit of particular lands.

Obviously, no set rules or operating procedure could be made generally applicable, even where a single agency, such as the Bureau of Reclamation, United States Department of the Interior (USBR), administers a number of irrigation systems. On each project special procedures must be developed to meet local physical and legal conditions without violation of the fundamental principles of efficient operation.

In some areas, where the need is not yet evident, little progress has been made in this regard; in others, such as the Salt River Project, where no waste of water can be countenanced, there is rigid control of all releases from storage, diversions to canals, and deliveries to farms.

Continuous Flow System

There are a few instances where "natural flow" rights must be complied with literally, and water must be delivered continuously to farms at the rates

and for the periods of time fixed by such rights. However, because this procedure is so wasteful of water and so conducive to improper practices, it has been supplanted generally by a system of temporary exchanges among holders of rights of approximately equal priority. In such cases one farmer on a ditch uses two or three times his quota for a few days and then takes no water while his neighbors are irrigating their land.

On some projects where the stream flow is now regulated, the system of continuous deliveries has been abandoned completely, and the quantities of water due under "natural flow" rights are accured for a few days and then delivered later on demand. For example, on the Salt River Project the water to which these rights apply is accrued for eight days, but must be used during the ensuing eight-day period.

Demand System

It is the natural desire of farmers that water be delivered to them on demand—that is, in the quantities and at the times deemed most desirable by each individual. This is a convenient system of operation and, if costs of construction and waste of water could be disregarded, no other operating procedure would be necessary. It is commonly followed during the early life of irrigation systems, but there is probably no fully developed project in the world where the collective demands of farmers could be met without overtaxing the capacity of the irrigation works and without causing excessive waste of water.

Even where it is practicable to make deliveries to farms on demand, advance notice should be required and other reasonable limitations on the time and rate of delivery of water should be enforced from the beginning. Otherwise, the imposition of controls, when the necessity arises, will be resisted as an infringement of a vested right.

Rotation System

When the Reclamation Act of 1902 was enacted and the United States undertook the construction of irrigation projects, it was with the primary intention of developing land then owned by the federal government. Farmers who settled on these raw lands had to clear, level, and otherwise prepare them for irrigation, in addition to assuming the burden of repaying the costs of construction of the irrigation works. Consequently, economy of construction was a governing consideration on these public projects.

It was recognized by all that, if water were delivered to farms in rotation at regular intervals rather than on demand, economies could be effected because smaller canals could be used. Accordingly, several projects were designed and built to be operated in this manner. In some cases rotation was to be limited to the farms served from each lateral, maintaining at least one irrigation head in every lateral; in others, laterals were to be served in rotation; and occasionally canals were to be operated intermittently, particularly during the spring and fall when water is used less than at the peak of the irrigation season. Similar principles have been followed in the design of many nonfederal irrigation systems to minimize capital costs.

In practice, however, the delivery of water in accordance with a predetermined schedule of rotation was not effective on most projects. When these systems were first put in operation, only a small part of the land was ready to receive water and many years elapsed before full development.

In the meantime, there was no need to regulate either the quantity of water delivered to a farm or the time at which it was delivered. Farmers naturally found it more convenient to irrigate in the daytime and during the middle of the week than to conform to a schedule requiring irrigation at night and occasionally on Sundays and holidays. Hence, it became customary to supply water as requested by the farmers. They naturally were unwilling to forego this privilege when the time came that their collective demands for water exceeded the capacity of the canals. Then, of course, the engineers were blamed for designing inadequate works, and pressure was brought to have the system enlarged.

Water Orders

In most well established projects a compromise procedure of water deliveries has been developed which retains many of the advantages of the rotation system, while recognizing that the need for water on individual farms varies considerably, depending on climatic conditions, the nature of the soil, and the character and stage of development of the crops planted. In principle, each farmer is required to anticipate his needs so that there will be time enough to schedule deliveries in rotation.

Normally, requests for the delivery of specified quantities of water are placed by individual farmers with the zanjero, or ditch rider, three or four days in advance. The zanjero assembles similar water orders from other farmers on the laterals operated by him and adjusts conflicts as to time of delivery. He then transmits to his watermaster a request for the delivery into these laterals of the quantity of water which he will need two or three days later to fulfil these demands.

The watermaster, who may have control of a canal serving a dozen laterals, receives similar requests from each of the zanjeros under his jurisdiction. He assembles these and schedules the diversion of water into the several laterals to minimize fluctuations in the feeder canal. After allowance for losses in transmission and other factors, he then transmits to his superior an order for the diversion into his canal of the water necessary to supply the laterals and, in turn, the farms needing water. The senior watermaster (or superintendent as the case may be) compiles these canal orders and determines when and how much the release of water from storage, or the rate of diversion into the canal systems, must be increased or decreased so that just enough water will be available as needed for diversion into the canals and from these into laterals and from the laterals to the farms.

Even under most favorable conditions, good judgment and long experience are needed to fulfil such water orders without undue waste. Consideration must be given to the time required for water to flow from a reservoir to points of diversion and from there through the canals and laterals to the farm headgates. Such times of transit vary markedly depending on the quantity that was

flowing in the stream and canals prior to the change and also on the degree of the change in flow. Channel storage also must be taken into account, because a part of any increased outflow from storage will be absorbed and a decrease will be offset in part by changes in the level of the water in streams and canals.

Operating Waste

Irrespective of whether the operating procedure involves the delivery of water on demand, in rotation, or in accordance with scheduled water orders, sudden climatic changes almost invariably cause operating waste of water.

On the Rio Grande Project, for example, it requires about four days for water released from storage to reach the lowest point of diversion. This region is characterized by sudden changes in temperature and humidity, frequently accompanied by thunderstorms, which cannot be predicted with any certainty four days in advance. When such storms occur in the valleys above El Paso, Tex., the use of water is immediately curtailed, because the farmers naturally refuse to take delivery of water when their ground is already wet. This reaction, of course, results in an increase in the water wasted from canals serving this part of the project. As the normal volume of operating waste from the upper units of the project was taken into account in scheduling the supply for El Paso Valley, the superintendent of the lower unit suddenly finds himself with more water at his diversion point than he ordered, and he has no choice but to permit it to waste downstream. At other times, operating waste from this part of the project becomes unavoidable, because an inch or more of rain falls in El Paso Valley just as the water previously ordered reaches the diversion point.

Conversely, when there is a sudden rise in temperature and a decrease in humidity, transpiration of plants and evaporation from land and water surfaces are increased; less water then reaches El Paso than was expected. The natural answer would be to guard against a shortage and to have always enough water in the river to meet all possible diversion demands. Unfortunately, this cannot be done because the total supply available to the Rio Grande Project is limited and excess operating waste in one year can be overcome only by rationing deliveries of water in subsequent years.

Most other large irrigation projects have similar problems because of climatic changes. Only occasionally would it be feasible to reduce the operating waste of water to the extent that has been done on the Salt River Project where about one third of the total supply of water is obtained from wells. These wells are so spread throughout the irrigated valley that, when any sudden decrease in the demand for water occurs, the well pumps can be shut off and the flow of water in the distribution system can be made to match the lessened demand. Seldom must the rate of outflow from the reservoirs be changed, except to conform to scheduled changes in the use of water.

On the other projects it has been found practicable to provide storage basins at the ends of primary canals in which the excess water may be impounded, until the canal flow can be adjusted to the demand, and from which this water can later be withdrawn for irrigation use.

Measurement of Water

The release, diversion, and delivery of water must be controlled if the reasonable demands of farmers are to be met without undue waste. Such controls cannot be imposed intelligently without good measurements of both the quantities of water in storage and the quantities released from storage and then diverted from streams, passed from canals into laterals, delivered to farms, and wasted at the ends of the system. On some projects, particularly those where water rights are in dispute, the inflow to reservoirs, the volume in storage, the release from storage, and the quantities of water diverted are measured consistently and with reasonable accuracy. On a few exceptional projects, passable records are kept of the water diverted from canals into laterals; but, with the exception of those systems where water is so valuable as to require distribution through pipe lines, measurements of water delivered to farm headgates are generally little better than guesses.

More complete and accurate hydrographic records are kept on the Salt River Project than on any other large project in the United States. The inflow to and the outflow from each reservoir are measured, and a record is kept of all fluctuations in storage. Gaging stations are operated on both the Salt River and the Verde River below all reservoirs and on each of the canals just below the diversion dam. Where these canals branch, enough measurements are made so that the quantity of water diverted into laterals can be estimated with reasonable accuracy. Records are also kept of the water pumped into canals. However, in spite of the completeness of such hydrographic data, an unreasonable proportion of the total supply remains unaccounted for by charges for water delivered to farms.

The practice of delivering more water to farms than is actually charged to water users is accepted almost everywhere as being reasonable and proper. Only recently has it been recognized that water rights are thereby being jeopardized. Recently (1950), for example, the State Water Board of Texas granted an application by the City of El Paso to appropriate certain waters of the Rio Grande. This application was based in considerable part on the apparent availability of waste waters. Actually most of the presumed excess supply of water was used beneficially for irrigation but it was not accounted for in the records of deliveries to farms in the El Paso Valley.

If the quantity of water delivered to farms were measured accurately, the magnitude of wastes and seepage losses from canals and laterals would not be exaggerated and the quantity of water required for beneficial use in the irrigation of land could be evaluated accurately. Better methods of measuring the flow of water from laterals through farm headgates are needed.

Maintenance of Works

Efficient operation of irrigation projects depends on all the works being kept in a good state of repair. As stated in a manual of the USBR:

> "The maintenance of irrigation projects is a highly important function, and essentially a technical job requiring a competent and experienced organization. Sufficient equipment and machines to accomplish the necessary

work shall be available at all times, commensurate with cost. Shop facilities for the repair and overhaul of machinery and equipment must also be provided. The water users are entitled to water delivery service from year to year with but minor interruptions."

Wherever water is used to irrigate land, there is the problem of removal and disposition of the portion not consumed by the plants or evaporated from the surface of the ground. This may be an operating function, or it may be a maintenance problem, depending on the manner in which the area is drained. In the Salt River Valley, the water that seeps out of canals and percolates downward from irrigated fields is removed by pumping from wells, there being very few open drainage channels. In most other projects, waterlogging of the land is prevented by a network of open drains. Their operation is automatic, but maintenance of these channels is a major problem because of the tendency for them to become clogged with silt or aquatic vegetation.

The problems of maintenance are too varied to permit more than reference to some of them—such as repair of frost damage, removal of silt deposits, and control of weeds and aquatic plants.

Frost Damage.—There are few irrigation projects in the United States where some structures are not subject to damage by alternate freezing and thawing, such as the spalling of concrete on the face of a dam and the heaving of pavement slabs in spillways and other concrete-lined channels. Some of the effects of ice and of alternate freezing and thawing can be obviated in the design of structures; others can be minimized by care in construction. However, repair of damage from such causes is a substantial part of the maintenance expense on most projects in northern climates.

Removal of Silt.—On many irrigation systems, the removal of silt deposits constitutes the greatest item of maintenance. For example, before Hoover Dam was constructed on the Colorado River, the removal of silt from the headworks and canals in Imperial Valley was a never-ending battle. The water diverted from this river carried with it in suspension many millions of tons of silt and sand each year. Some of this was caught in settling basins just downstream from the headworks and removed by dredges which operated continuously; the greater part, however, passed on down the canals, and it was only by keeping these full and by wasting the excess water into channels which flowed to Salton Sea that the deposition of silt could be controlled reasonably. Even so, it was necessary to keep draglines, "Ruth" dredges, and other excavating equipment in operation on every canal. The maintenance expense was so great as to jeopardize the economic stability of the project.

In the Middle Rio Grande Valley of New Mexico it has not been possible to keep the irrigation system in good operating condition because of the volume of sand and silt carried by the river. Large reservoirs to intercept these sediments must be constructed if the rate of deposition is to be kept within reasonable bounds. Elsewhere the problem is generally less acute.

Control of Vegetation.—Except for the few irrigation systems where water is obtained from wells and distributed in closed conduits, the control of weeds and aquatic vegetation is a universal maintenance problem.

Some grass or other vegetation is desirable on ditch banks and other earth slopes to prevent erosion, but it cannot be left to grow uncontrolled. Sooner or later objectionable grasses, weeds, willows, or other plant pests too numerous to mention take root and persist in spite of all preventive efforts. The best that can be done is to keep such growths reasonably under control.

Aquatic plants, such as tules, cattails, and water hyacinth, are not normally much of a problem in the maintenance of canals, but they thrive in the clear water of drainage channels. Drains can become almost nonoperative in a surprisingly short time if maintenance is deferred.

Moss will frequently form and almost clog canals where the water is clear. Under favorable conditions of temperature and sunlight the growth of moss is rapid; streamers 20 ft to 30 ft long are not uncommon. Raking or cutting this moss free is only part of the problem because it comes to the surface and floats downstream where it tends to clog gate openings, etc. Hence, while one crew is cutting it free, another maintenance crew must be stationed downstream to remove it from the canal.

Occasionally, and for no apparent reason, some new type of growth will make its appearance, requiring almost heroic measures to keep it under control. This was the case in the Imperial Valley shortly after the silt problem was solved by the construction of Hoover Dam. A species of bamboo began to grow on the canal banks and to send out roots for great distances, from which other clumps of bamboo would sprout.

The growth of tamarisk, or salt cedar, is another example of plant infestation which has added to the maintenance problems of many irrigation systems. Before 1920 it was almost unknown; now it grows so thickly in many places as to be almost impenetrable. The consumption of water by tamarisk is about the same as the evaporation loss from a free water surface. Consequently, the eradication (or at least the control of it) constitutes a substantial maintenance problem for which no definite remedy has yet been found.

Methods of controlling weeds and other undesirable vegetation along canals and around reservoirs differ widely depending on conditions peculiar to the area. On some projects, particularly those where the removal of silt deposits is necessary, canals are generally cleaned by mechanical methods. On others, burning with flame throwers has been found successful and reasonably economical. Chemical spraying is favored in some areas and probably will become more generally adopted as better sprays are developed and better equipment is manufactured.

Machinery and Equipment

In this connection, the need for machinery and equipment designed for cleaning canals and drains has been unrecognized, although the amount of money spent annually in the maintenance of canal systems is great enough to justify the development of special machines. Tremendous strides have been made in the development of excavating equipment for use in construction because of contractors who, under the whip of competition, demand greater speed, efficiency, and ease of control. Those who maintain irrigation systems still struggle along with makeshift adaptations of equipment designed for other

purposes. Perhaps this is because irrigation projects are separate entities, among which there is little competition, and the cost of maintenance is looked upon as a burden to be borne with resignation.

Costs and Cost Accounting

Little effort is generally made to allocate costs of operation and maintenance. Even the manuals of the USBR are substantially silent in this respect, although many millions of dollars are spent each year on federal reclamation projects alone for such purposes.

This apparent lack of interest in cost accounting presumably arises from the fact that irrigation projects are operated in effect as cooperatives. Under ordinary circumstances, the cost of labor of all classes is estimated for the year, and to this is added the probable cost of materials and supplies and equipment to be purchased. Estimates are also made of the probable revenue from water sales, if any, and of other incidental revenues. The difference between the total estimated cost and the estimated direct revenues is then charged to the water users in the form of assessments per acre or taxes assessed against all property within the project. Such budgetary accounting is not sufficient for proper control of costs.

In 1940, when economic conditions were reasonably stable, the combined cost of operation and maintenance on typical federal reclamation projects was as follows:

Project	Area, in acres	Cost per acre
Milk River, Montana	117,400	$0.69
Belle Fourche, North Dakota	61,000	0.85
Minidoka, Idaho	68,900	1.48
Boise, Idaho	166,400	1.20
Yakima, Washington	165,500	1.87
Rio Grande, New Mexico and Texas	142,800	2.40
Yuma, California and Arizona	67,400	2.26
Salt River, Arizona	243,000	1.75

These costs are no measure of what must be spent today to operate and maintain an irrigation project in good condition. For example, the total cost for such functions was reported to have been only $414,350 on the Salt River Project in 1940, whereas the total reported for 1948 was $2,433,302 (see Table 1).

This total cost, equal to practically $10.00 per acre, is exclusive of $393,393.89 set up on the books as depreciation accrued in that year on irrigation properties in service. For comparison with the reported cost in 1940, the charge made for power used in pumping should be deducted in Table 1. This was $728,866 computed at the same rates as for power sold to others. Even on this basis, the direct costs of operation and maintenance of the Salt River Project quadrupled from 1940 to 1948.

The impact of changed economic conditions has been less on most other projects up to the present time, principally because they have not had to conform to federal labor laws. As these become applicable to such other

projects, which should be anticipated, their costs of operation and maintenance must likewise increase tremendously. In this connection the Supreme Court of the United States on June 27, 1949, held that a mutual water company was subject to the provisions of the wage and hour acts (the Farmers Reservoir and Irrigation Company versus William R. McComb, Administrator of the Wage and Hour Division, 17 LW 4688).

TABLE 1.—OPERATING EXPENSES OF THE IRRIGATION DEPARTMENT, SALT RIVER PROJECT, FOR THE YEAR ENDING DECEMBER 31, 1948

Item (1)	Class of expense (2)	Operation (3)	Maintenance (4)	Total (5)
1	Surface water production	$ 40,853.16	$ 15,099.88	$ 55,953.04
2	Ground water production	775,837.08	58,260.62	834,097.70
3	Purchased water	10,440.81	....	10,440.81
4	Transmission expense	52,570.38	71,151.76	123,722.14
5	Distribution expense	461,519.43	426,129.47	887,648.90
6	Drainage expense	43,167.24	126,915.56	170,082.80
7	Subtotal	$1,384,388.10	$697,557.29	$2,081,945.39
8	General expenses not allocated	....	....	351,356.84
9	Total: Irrigation, operation, and maintenance	....	....	$2,433,302.23

SUMMARY

Inasmuch as the foregoing has been little more than a summary of the problems of operation and maintenance of irrigation systems, it seems appropriate to close with only a restatement of the basic principles that govern their solution: Efficient operation is defined as the delivery of enough water to each farm at the right time to satisfy all beneficial needs without waste. It depends on the maintenance of all storage, diversion, distribution, and drainage works in good condition at all times.